Some Unique Benefits with Sudangrass for Improved U.S. #1 Yields and Size of Russet Burbank Potato

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ABSTRACT

Three studies provided additional knowledge of beneficial effects of sudangrass for yield and quality increases of the Russet Burbank potato. Two of these studies showed significant increases of both U.S. #1 and smooth tubers >280 g following green manures of sudangrass. These sudangrass (HS-33) effects did not differ from a sorghum-sudan hybrid (Trudan-8). When a sudangrass green manure was compared with a fallow treatment, results of the first study showed mean yield increases of 36% for U.S. #1 tubers >280 g and yields of a second study by 34% for U.S. #1 tubers. This same sudangrass treatment outperformed green manures of either Austrian winter pea, barley, or sweet corn by increased U.S. #1 yields that ranged from 27% to 61%. By several lines of evidence, these benefits were found to extend beyond the effect of Verticillium suppression. Soil N was significantly increased following green manures of sudangrass, and these increases were in turn negatively correlated with wilt incidence and positively correlated with yields of both U.S. #1 tubers and tubers >280 g. Additional benefits also included significant increases of tuber grade percentages for marketable tubers and of smooth tubers >280 g. Benefits from sudangrass green manures beyond the effects of Verticillium suppression became further evident following a greenhouse study that involved field soil and sudangrass that had been grown in the same field. This study corroborated both field experiments by showing increased yields with green manures of sudangrass that approximated 5.5 t ha^{-1} dry wt. As with the field studies, these yield benefits also extended beyond the effects of Verticillium suppression and were closely associated with significant increases of *Fusarium equiseti, F. oxysporum*, and *F. solani*. Throughout all studies, sudangrass green manures significantly increased microbial activities with increased populations of *Fusarium* spp. and increased concentrations in soil of mineralizable N, organic P, K, Mn, along with the percent soil organic matter — all factors that could have contributed to significant increases of yield and quality.

RESUMEN

Se obtuvo información adicional sobre los efectos benéficos del sorgo para el incremento de rendimientos y calidad de papa Russet Burbank por medio de tres estudios. Dos de ellos mostraron un significativo incremento de U.S. #1 y tubérculos uniformes >280g después de haber recibido sorgo como abono verde. Los efectos del sorgo (HS-33) no mostraron diferencias con el sorgo híbrido (Tridan-8). Cuando se comparó el abono verde de sorgo con un tratamiento de barbecho, los resultados del primer estudio mostraron un promedio de incremento del rendimiento de 36% para tubérculos U.S. #1 >280g y los del segundo estudio 34% para tubérculos U.S. #1. El mismo tratamiento de sorgo, superó a los abonos verdes de alverjilla, cebada y maíz dulce con rendimientos de U.S. #1 que variaron entre 27 y 61%. Junto con estas evidencias, los beneficios logrados fueron además un efecto de supresión de Verticillium. El

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N del suelo se incrementó significativamente después de un abonamiento verde con sorgo y este incremento estuvo negativamente correlacionado con la incidencia de marchitez y positivamente con el rendimiento tanto de U.S. #1 como de tubérculos >280g. Los beneficios adicionales también incluyen un incremento significativo del porcentaje de tubérculos de grado comerciable y de tubérculos uniformes >280g. Además de los efectos de supresión de Verticillium, los efectos del abono verde con sorgo se hicieron evidentes después de un estudio de invernadero que incluyó el uso de tierra de chacra y de sorgo que había crecido en el mismo suelo. Este estudio corroboró ambos experimentos de campo, mostrando un incremento de rendimiento de aproximadamente 5.5 t ha^{-1} de peso seco con el uso de sorgo como abono verde. Como en el caso de los estudios de campo, estos beneficios en el rendimiento también se extendieron más allá de los efectos de supresión de Verticillium y estuvieron estrechamente asociados con un incremento significativo de *Fusarium equiseti, F. oxysporum* y *F. solani.* A lo largo de todos los estudios, el uso de sorgo como abono verde incrementó significativamente las actividades microbianas, con un aumento en la población de *Fusarium* spp. e incremento de las concentraciones de N mineralizable, P,K y Mn orgánicos, junto con el porcentaje de materia orgánica en el suelo, factores todos que podrían contribuir a un aumento de rendimiento y calidad.

INTRODUCTION

Among cropping practices, green manures can be highly effective for both the control of Verticillium wilt caused by *Verticillium dahliae*, and the improvement of yield and quality of potato (Davis et al. 1996; Huisman et al. 1995). Green manure crops that have provided disease suppression include barley, corn, rape, oats, rye, sudangrass, and wheat (Davis et al. 1996, 1999a, 1999b), but of these crops, sudangrass has to date provided the greatest yield response of U.S. #1 tubers and tubers >280 g with potato. Although the benefits of sudangrass on Verticillium wilt suppression cannot be directly explained by a reduction in soil populations of *V. dahliae*, these benefits can be explained by a reduction in number of root infections by *V. dahliae* (Davis et al. 1996).

Benefits from sudangrass, however, may extend beyond disease suppression (Davis et al. 1996). When a green manure crop of either oats or sudangrass was grown and incorporated for 2 years prior to a potato crop, the incidence of Verticillium wilt did not differ between these two green manures. Yet, tuber yields following sudangrass were significantly higher when compared to oats. This occurred even though the amount of green residue incorporated with the oats was greater than with sudangrass. A similar relationship between corn and sudangrass also occurred. Even though wilt incidence and *V. dahliae* colonization did not differ between green manure treatments of corn and sudangrass, there was still a significant increase of tuber size of smooth tubers >280 g by 22% with sudangrass. The purpose of this study was to further investigate the effect of sudangrass on yield and quality of potato and its relationship to *V. dahliae.*

MATERIALS AND METHODS

Field studies were conducted at the University of Idaho Research and Extension Center, Aberdeen, ID, on a Declo loam soil with a pH of 8.0 to 8.2. Prior to 1992, the cropping histories of both fields included potatoes and small grains for >30 years.

Biomass Field Study with Sudangrass (Roots vs Foliage)—Experiment 1

Green manure treatments were arranged and grown for two consecutive years (1992 and 1993) in a 4 x 4 Latin square design on plots that were 5.5 x 15.2 m in size. Main plot treatments were split with a split-plot factorial design consisting of two sudangrass (*Sorghum vulgare* Pers. var. sudanense [Piper] Hitchc.) varieties: HS-33 (CalWest Seeds, Woodland, CA) and Trudan-8 (Northrup King, Minneapolis, MN). Main plot treatments were (1) a weed-free fallow; (2) foliage of sudangrass that was removed and roots incorporated; (3) a fallow to which sudangrass cuttings were added; and (4) foliage and roots incorporated. Green manures were planted during last week of May each year and were incorporated by plow or rotovator in mid-August.

In both years, prior to incorporation of green manures, samples were collected from 1 m^2 of the buffer regions of each plot to provide an estimate of foliage residue to be incorporated into soil. These foliage samples were oven-dried at approximately 49 C for 2 wk before making weight determinations. The mean dry weights of sudangrass ha^{-1} for HS-33 and Trudan-8 were 11 and 12 tons, respectively, in 1992 and 5 tons ha^{-1}

in 1993 for both HS-33 and Trudan-8. Weed control in plots was provided with applications of 2,4-D (water soluble amine) at 0.56 kg ha^{-1} in mid-June. Broadcast fertilizer applications of ammonium nitrate, phosphate, and triple superphosphate were based on soil assays taken prior to planting of both green manures and potatoes in the spring of each year (University of Idaho Soils Lab, Moscow, ID).

Certified, uncut seed (single drop) of cv Russet Burbank and cut seed (59 ± 6 g) of cv Russet Norkotah were planted with an assist-feed planter in 3-row plots in 10.7-m row lengths during the first week of May 1994. Row width was 0.9 m and seed was spaced 30 cm apart in rows.

No systemic insecticides were applied, and all irrigations were applied with solid-set sprinklers. In general, cultural practices were as recommended by the University of Idaho for potato production (Anonymous 1986; Bishop et al. 1982; Kleinkopf et al. 1981; Ohms 1962; Westermann et al. 1994). Foliar sprays of either mancozeb at 1.8 kg ha^{-1} or chlorothalonil at 1.25 kg ha^{-1} were applied at weekly intervals between mid-July and 1 September to protect against foliar diseases (early blight and black dot) that can reduce yield (Anonymous 1986; Mohan et al. 1992).

Biomass Field Comparisons of Sudangrass with Several Green Manures—Experiment 2

Green manure crops were grown for two consecutive years (1995 and 1996) on plots (18.3 x 7.3 m). Treatments consisted of (1) a weed-free fallow; (2) barley (*Hordeum vulgare* L. 'Russell'); (3) sweet corn (*Zea mays* L. 'Jubilee'); (4) Austrian winter pea (*Pisum sativum* L. 'Melrose'); and (5) sudangrass (clone HS-33 from Cal-West Seeds, Woodland, CA). Treatments were arranged in a 5 x 5 Latin square design.

In 1995, seed was planted by grain drill on 13 April (Austrian winter pea), 30 May (sweet corn), 15 May (barley), and 30 May (sudangrass). With the exception of the pea plots, all plots were sprayed with 2,4-D (water soluble amine) at 1.2 L ha^{-1} on 27 June, and Basagran (bentazone) at 2.47 L ha^{-1} was applied to peas on 8 July. Peas and barley were incorporated by rotovator on 11 July, and the corn and sudangrass were incorporated on 21 August. Nitrogen was injected through a solid-set sprinkler system to provide 45 kg ha^{-1} of N on 28 June, and an additional 45 kg ha^{-1} was applied following incorporation on 31 August. In 1996 the same procedure was followed.

Fertilizer applications were based on pre-plant soil test determinations and estimates of dry weights of green manures were determined as previously described. The mean green manure dry weights ha^{-1} for 1995 and 1996, respectively, were as follows: peas, 6 and 5 t; barley, 10 and 14 t; corn, 12 and 11 t; and sudangrass, 12 and 13 t.

A broadcast application of metam-sodium (Vapam HL) was injected into plot areas on 17 April 1997, at 350 L ha^{-1}. Injections were made at two depths simultaneously (13 cm and 28 cm) with injections at 5 m per pass with a spacing between shanks of 38 cm.

Seven days before planting potatoes, the field was disked to hasten the removal of any remaining metam-sodium. A pre-plant application of N was also applied and incorporated at 90 kg ha^{-1}. During the growing season, N was injected through the lines on 30 June and 17 July at 45 kg ha^{-1}. Certified uncut seed of Russet Burbank (>50 g in size) was planted with an assist feed planter with a 30 cm spacing between seedpieces. Matrix (rimsulfuron) at 70 g ha^{-1} and Sencor (metribuzin) at 560 g ha^{-1} were applied on 29 May with a ground application for weed control. For insect control, Admire (imidacloprid) at 280 g ha^{-1} was shanked into the hill on 27 May. Thiodan (endosulfan) at 33 L ha^{-1} and Monitor (methamidophos) at 2.5 L ha^{-1} were applied. At season end, vines were killed with Diquat (diquat dibromide) at 3.3 L ha^{-1}. Beginning 5 July, Bravo (chlorothalonil) at 3.7 L ha^{-1} was broadcast applied by air at weekly intervals until 6 September 1997. The following sections describe data taken on both Experiment #1 and #2.

Disease Assessment

Wilt incidence was expressed as the percentage of potato stems with symptoms in uppermost 15 cm of the stems (50 stems randomly selected per plot). To separate Verticillium-like symptoms from other factors that may produce similar symptoms (e.g., drought stress, nutrient deficiency, senescence), the terminal 8 cm of stem tissue was assayed for *V. dahliae* as previously described (Davis et al. 1983). Depending on the disease occurrence, dates of taking data varied by experiment and year. In 1994 data were taken on 15 and 22 August and in 1997 owing to the later occurrence of symptoms, data were not taken until 26 and 29 August and 8 September.

Soil Assays for V. dahliae *and* Fusarium *spp.*

Soil samples were collected at pre-emergence of potatoes during the spring of each year (1994 and 1997) in field plots (12-14 samples per plot) from unplanted center areas in each plot from the upper 15 cm depth with a 2-cm soil probe. These samples were air-dried for approximately 6 wk at 20 to 25 C and then mixed. Six soil subsamples totaling 80 g were collected, further mixed, and passed through a 250-µm (60 mesh) screen to remove organic matter and to standardize particle size. Following a fourth consecutive mixing of soil, five subsamples (50 mg each) were plated onto five plates of NP-10 medium (Sorensen et al. 1991) using the Andersen sampler (Butterfield and DeVay 1977) for *V. dahliae* quantification and onto Komada medium (Komada 1975) for quantification of *Fusarium* spp. Plates were incubated at laboratory room temperature for 2 wk, washed under running tap water to remove soil particles, and respective colonies of *V. dahliae* and *Fusarium* spp. were counted with a binocular microscope and expressed as colony-forming units (cfu) per gram of soil.

Potato Root Assays

Five core samples from soil were taken as previously described (Davis et al. 2001) with a bulb planter (6 x 10 cm) from the row in each plot that was not used for harvest. Soil samples were collected in early July of each year. Root infections by *V. dahliae* and *Colletotrichum coccodes* were quantified by the procedure of Huisman (1988). Potato feeder roots of at least 1 cm in length were collected with tweezers from each soil sample. Roots were washed thoroughly in a solution of 1% sodium hexametaphosphate, 0.1% Tergitol NP-10 and rinsed in sterile water. Roots were then plated onto NP10 medium (Sorensen et al. 1991). After 2 wk the number of *V. dahliae*, *Colletotrichum*, and *Fusarium* colonies from the root cortex were counted and expressed as number of colonies per meter of root (cfu/m root).

Nutrient Analyses of Soil and Plant Tissue

Soil nutrients consisting of NO_3-N, mineralized N, inorganic P, K, Mn, Zn, Cu, and Fe were measured as described by Gavlak et al. (1994). Prior to planting potatoes, a minimum of eight soil cores (1.9 x 30 cm) from each plot were taken with a soil probe. Samples within a plot were bulked, mixed, air-dried, and ground before analyses.

A separate row in each plot was used for nutritional data. From this row whole plant samples (4-5) were collected from 1.5 m of plot row, and petiole samples (30 per plot) were collected from the first mature petiole in mid-July and August for both field studies. After drying and weighing, plant materials were analyzed as previously described (James et al. 1994).

Harvesting and Grading

Tubers were harvested from the center rows of each plot. Tubers were washed and graded according to standard methods (Anonymous 1971). In a separate row set aside for nutritional and growth data, plant materials that had been dug in July and August to measure nutrient uptake in tubers were weighed to evaluate the effect of treatments on plant growth.

Biomass Rate Study with Sudangrass (Greenhouse)—Experiment 3

Soil from experiment 1 with a known history of Verticillium wilt was diluted by mixing it with two parts of field soil, two parts of perlite, and five parts of sand by volume. Foliage from sudangrass (HS-33) grown in the field used for the root and foliage study was harvested in August, placed into burlap bags, and held at ambient greenhouse temperature conditions (18-30 C) for several months prior to study initiation. At this time foliage remained green, but had become dry to nearly dry in moisture content. The base amount of sudangrass added was 11 t ha^{-1} = rate x. The 1x rate was calculated at 20.0 g of dry sudangrass pot^{-1} to approximate 11 t ha^{-1}. Sudangrass was added to the soil mix at 0.0x, 0.25x, 0.50x, 1.0x, and 2.0x and dispensed into 2300-cc pots (15 x 18 cm). The experimental design was a randomized block with six replications per treatment. A total of 7.5 g of Morgro fertilizer of 6-10-4 (N, P, K) containing 1% iron and 2% sulfur was partially dissolved into 150 mL of distilled water and poured over the contents of each pot.

For 2.5 months the soil was occasionally irrigated (~70-80% ASM) while sudangrass was breaking down to prevent total drying and held at temperatures ranging from 18 to 30 C. Pathogen-free Russet Burbank pre-nuclear seed (minitubers) was planted into each pot on 22 February. All pots were irrigated with distilled water until plants had emerged. At that time distilled water was replaced with tap water. Libby Miller fertilizer 20-20-20 at 1.2 g L^{-1} was applied to each pot with 70 mL pot^{-1} at weekly intervals. The experiment was terminated when plants were 11 wk old. Stem sections (3 cm long) were taken from the soil line. Stems were rinsed under running tap water, dipped into 0.05% NaOCl for 10 sec, and air dried at ambient room temperature for 4 wk. The air-dried stems were ground in the Wiley Mill through a 40-mesh screen and plated with the Andersen sampler onto Sorensen's NP-10 medium (10 mg for each of five plates per sample). Plates were incubated at laboratory temperature (20-25 C) for at least 2 wk before determining the number of *V. dahliae* colonies. The soil from each pot was utilized for further analyses of *V. dahliae* and *Fusarium* populations as described in previous section.

Data Analyses

Percent infection was analyzed after arcsine-square root percent transformation. In all cases, means were calculated from the transformed data and reconverted to original units. The effect of treatments on changes in inoculum density per gram of soil over time was assessed according to a Latin square, split-plot, repeated-measures analysis (Kirk 1982). Because years occurred in sequence, the Greenhouse-Geisser adjustment was used to ensure that all comparisons between years were valid. All ANOVAs were conducted in accordance with each experimental design that was used (Steel and Torrie, 1960).

TABLE 1—*Effect of sudangrass green manure treatments on tuber yield of Russet Burbank potato (1994).*

Treatments	Yield (t ha^{-1})[a] Total	U.S. #1	Tubers >280 g	U.S. #1's >280 g
Fallow	52.8	33.5	16.6 B	12.0 C
Roots	51.9	35.0	20.0 AB	13.9 BC
Foliage	56.7	39.0	22.2 A	17.1 A
Roots and foliage	52.7	35.9	20.6 A	15.5 AB
	NS	NS		

[a]Different letters within columns denote significant differences at $P \leq 0.05$ level by Duncan's multiple range test.

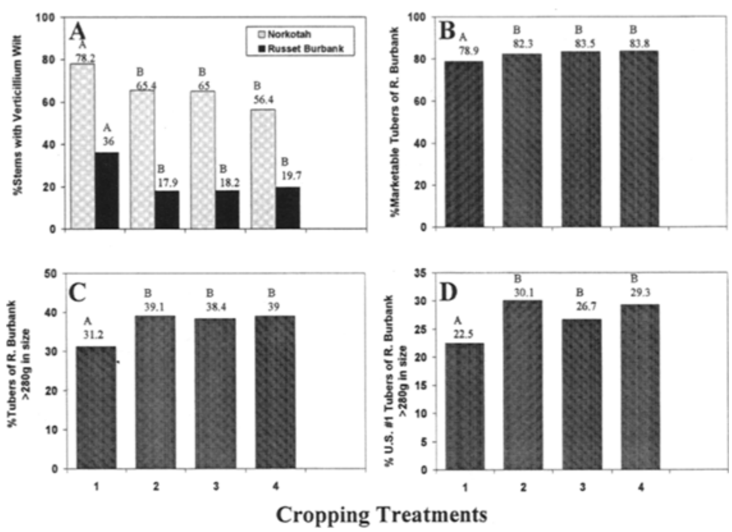

FIGURE 1.
Cropping treatment 1 – control (no sudangrass); treatment 2 – sudangrass roots remaining with all above-ground foliage removed; treatment 3 – sudangrass above-ground foliage incorporated as a green manure into fallow soil; treatment 4 – sudangrass above-ground foliage and roots incorporated into soil as green manure practice. A) Compares wilt incidence on Aug 15 for Russet Burbank and Aug 3 for Russet Norkotah. Yield responses were not evident with the early Norkotah variety. B-D) Show potato tuber, quality, and size from sudangrass when incorporated into the soil the previous fall.

RESULTS

Biomass Field Study with Sudangrass (Roots vs Foliage)—Experiment 1

Benefits of potato quality and size occurred from sudangrass even when the foliage was cut and removed from the field, leaving only the stubble and roots behind (Figure 1). Verticillium wilt was suppressed in both Russet Burbank and Norkotah (Figure 1a). Potato quality was improved on Russet Burbank (Figure 1b-d) but not Norkotah (data not shown). Significant increases occurred on Russet Burbank for percent marketable tubers, percent of large tubers >280 g (10 oz), and the percent of U.S. #1 tubers >280 g in size, but yields were not increased.

Yields of tubers >280 g were only increased following the addition of sudangrass foliage to either fallow soil or to soil with intact roots. Yields of tubers >280 g increased by 24% to 34% and U.S. #1s >280 g increased by 29% to 43% compared to the fallow control (Table 1). U.S. #1 potatoes >280 g growing in the fallow plots to which sudangrass had been added yielded 23% more than in plots where sudangrass was cut and removed. There were no differences in the effect of sudangrass varieties (HS-33 and Trudan-8) on either disease or potato yield (Table 2).

Fusarium equiseti *populations*: Throughout these studies, yields were positively correlated with *F. equiseti* soil populations from soil collected prior to planting potatoes (Table 4). As sudangrass was added to soil, the colonization of *F. equiseti* on potato roots and the soil populations of *F. equiseti* increased (Table 3). On two dates (15 and 22 August) wilt incidence was negatively correlated with soil populations of *F. equiseti* (Table 4).

Verticillium dahliae *populations*: Populations of *V. dahliae* g^{-1} of soil in the spring did not differ significantly between treatments (Table 3), but stem colonization by *V. dahliae* was correlated

TABLE 2—*Comparative effects of green manures of sudangrass (HS-33) and a sorghum-sudan hybrid (Trudan-8) on incidence of Verticillium wilt and yields of two potato varieties.*

Potato Variety	Green Manure	% Wilt Incidence		Yield t ha^{-1} Total	U.S. #1	Tubers >280 g	U.S. #1's >280 g
Russet Burbank		15 Aug	22 Aug				
	HS-33	21	48	52.5	35.0	19.2	14.0
	Trudan-8	25	46	53.0	35.6	19.9	14.8
		ns	ns	ns	ns	ns	ns
Russet Norkotah		20 Jul	3 Aug				
	HS-33	9	66	43.8	35.4	11.6	11.3
	Trudan-8	10	67	44.3	35.8	12.3	12.0
		ns	ns	ns	ns	ns	ns

TABLE 3—*Effect of sudangrass green manure treatments on incidence of Verticillium wilt of Russet Burbank, soil populations, and potato root infections by* Verticillium dahliae *and* Fusarium equiseti *(1994).*

Application treatments	% wilt incidence 15 Aug	Root populations (cfu m^{-1} root)[b] *V. dahliae*	*F. equiseti*	Soil populations (cfu g^{-1} of soil)[c] *V. dahliae*	*F. equiseti*
Fallow	36 A[a]	10.6	6.5 B	34	410 D
Roots	18 B	7.8	15.9 B	52	840 C
Foliage	18 B	8.8	34.9 A	48	1320 B
Roots and foliage	20 B	8.0	39.5 A	33	1660 A
		NS		NS	

[a]Different letters within columns denote significant differences at $P \leq 0.05$ level by Duncan's multiple range test.
[b]Assays made from roots collected in July 1994.
[c]Soil collected 18 April 1994, prior to planting potatoes.

TABLE 4—*Correlation (r-values)*[a] *between microbial populations, wilt incidence, and yield of Russet Burbank potato–Experiment 1.*

Disease and Pathogen variables	Source	% Wilt incidence on given dates 15 Aug	22 Aug	Yield relationships of tubers Total	U.S. #1	U.S. #1 >280 g	>280 g	n
Verticillium dahliae	soil	0.206	0.245	-0.009	-0.047	-0.138	-0.055	30
V. dahliae	root	0.583***	0.629***	-0.025	-0.016	-0.154	-0.197	30
V. dahliae	stem	0.402*	0.406*	-0.353*	-0.112	-0.200	-0.320	30
Fusarium avenaceum	soil	0.043	-0.050	-0.187	-0.128	0.036	0.063	30
F. equiseti	soil	-0.394*	-0.495**	0.169	0.350*	0.435*	0.366*	30
F. equiseti	root	0.005	-0.026	-0.031	0.157	0.170	0.083	30
Fusarium. oxysporum	soil	-0.166	-0.135	0.343*	0.441**	0.338	0.279	30
F. oxysporum	root	0.055	0.090	-0.127	-0.283	-0.330	-0.260	30
Fusarium solani	root	-0.281	-0.226	-0.140	-0.035	-0.077	-0.050	30
Colletotrichum coccodes	root	0.117	0.118	0.194	0.006	-0.106	-0.051	30
Microbial activity[b]	soil	0.125	0.069	0.249	0.390*	0.244	0.214	30
% wilt 15 Aug		—	—	-0.477**	-0.420*	-0.551***	-0.604***	30
% wilt 22 Aug		—	—	-0.394*	-0.343	-0.499**	-0.565***	30

[a]*, **, and *** indicate $P \leq 0.05$, 0.01, and 0.001, respectively.
[b]Measured by fluorecein diacetate procedures.

TABLE 5—*Correlations (r-values)*[a] *between nutrients, wilt incidence, and yield of Russet Burbank potato—Experiment 1.*

Nutrient variables in soil April 18	% Wilt incidence on given dates: Aug 15	Aug 22	Yield relationships of tubers: Total	U.S. #1	U.S. #1 >280 g	>280 g	n
NO_3-N	-0.601***	-0.597***	0.158	0.156	0.389*	0.382*	30
Mineralized N	-0.576***	-0.667****	0.207	0.273	0.352*	0.331	30
P inorganic	-0.268	-0.258	0.449**	0.284	0.224	0.180	30
P organic	-0.061	0.035	0.355*	0.134	0.065	0.093	30
K	-0.273	-0.326	0.564***	0.469**	0.497**	0.462**	30
Mn	-0.298	-0.338	0.425*	0.282	0.202	0.196	30
Zn	-0.097	0.013	0.510**	0.398*	0.152	0.207	30
Cu	-0.333	-0.221	0.293	0.072	-0.044	0.007	30
Fe	-0.071	-0.035	0.404*	0.180	0.082	0.116	30

[a]*, **, ***, and **** indicate $P \leq 0.05$, 0.01, 0.001, and 0.0001, respectively.

TABLE 6—*Effect of sudangrass treatments on soil nutrient concentrations.*

Application treatments	Residual nutrients in soil (ppm)[xy] prior to planting potato: NO_3-N	Mineralized N	Inorganic P	Organic P	K	Mn	Zn	Cu	Fe
Fallow	18.5[z] B	19.4 C	34.7 B	5.7 A	279.4 B	8.6 B	1.2 A	1.0 A	6.9 A
Roots	19.9 B	24.9 B	29.6 C	6.4 A	237.0 C	9.3 A	1.2 A	1.2 A	7.6 A
Foliage	24.0 A	26.4 A	37.9 A	5.7 A	356.4 A	9.4 A	1.3 A	1.0 A	7.0 A
Roots and foliage	22.6 A	27.2 A	28.6 C	5.6 A	292.0 B	9.4 A	1.1 A	1.0 A	6.7 A

[x]Observed in upper 0.3 m in spring prior to planting potatoes.
[y]Values represent means of Trudan-8 and HS-33 plots. Residual nutrient levels did not differ significantly between the Trudan-8 and the HS-33 plots.
[z]Different letters denote significant differences at $P \leq 0.05$ level with Duncan's multiple range test.

TABLE 7—*Effect of green manures on Russet Burbank, yield, quality, and size (1997).*[a]

Cultivar and green manure treatments	Yield (t ha^{-1})[b]: Total	U.S. #1	Tubers >280 g: Total	U.S. #1
Russet Burbank				
Fallow	45.0	29.7 B	12.7	9.8 B
Austrian winter pea	41.8	24.8 B	12.2	8.7 B
Sudangrass	51.1	39.9 A	15.4	13.4 A
Barley	45.2	31.4 B	11.2	9.1 B
Sweet Corn	43.7	29.5 B	13.7	10.9 AB
	NS		NS	

[a]Treatment comparisons were made on ground pre-treated with metam sodium at recommended rate (350 L ha^{-1}).
[b]Different letters within columns denote significant differences at $P \leq 0.05$ level by Duncan's multiple range test.

with wilt (Table 4). On two different dates (15 and 22 August) populations of *V. dahliae* from stems and roots were positively correlated with wilt incidence (Table 4). Although root populations of *V. dahliae* failed to correlate with total yield, a significant correlation occurred between stem populations and total yield. Neither stem nor root populations of *V. dahliae* correlated significantly with yields of U.S. #1 tubers >280 g.

Correlations of nutrients with wilt and yield: Yield response and improved tuber grade were closely associated with significant increases of mineralizable N and of Mn, P, K, Zn, and Fe (Table 5). The incorporation of sudangrass foliage or foliage and roots increased the concentreations of soil nitrate N, mineralizable N, Mn, and K (Table 6). Increases in mineralizable N and Mn occurred even following the cutting and removal of sudangrass foliage from the field. As sudangrass foliage was added to soil, the residual nutrient levels increased, and with these increases, the yields of larger tubers >280 g also increased (Table 1) along with higher percentages of U.S. #1 tubers (Figure 1).

Biomass Field Comparisons of Sudangrass with Several Green Manures—Experiment 2

Among the green manures, only sudangrass increased yield of U.S. #1 tubers and yield of U.S. #1 tubers >280 g in Russet Burbank (Table 7). U.S. #1 yields were 34% higher than the fallow treatment and 37% higher for larger U.S. #1 tubers >280 g in size.

TABLE 8—*Effects of green manures on metam sodium treated land on wilt incidence and populations of* V. dahliae *and* F. equiseti.

Green manure treatments	Wilt incidence Aug 26	Sep 8	*V. dahliae* populations in apical stems of R. Burbank (ln cfu g^{-1} of stem)	cfu g^{-1} of soil *V. dahliae*	*F. equiseti*
Fallow	27 A[a]	47 A	2.72[b]	7.2[c]	125 D[d]
Austrian winter pea	16 B	34 B	2.04	8.8	387 C
Sudangrass	11 B	30 B	1.40	16.8	541 B
Barley	7 C	22 C	1.40	14.4	861 A
Sweet corn	5 C	15 C	1.11	12.8	774 AB
			NS	NS	

[a]Different letters denote significant differences between treatments to $P \leq 0.05$ with Duncan's multiple range test.
[b]Stem colonization highly correlated with AUDPC @ $P = < 0.01$ (r = 0.558).
[c]Not significantly correlated with AUDPC.
[d]Soil populations of *F. equiseti* highly correlated (negatively) with AUDPC @ $P = < 0.01$ (r = -0.585).

TABLE 9—*Effects of green manures on metam sodium treated land on soil nutrients.*

Green manure treatments	Soil nutrients – preplant 1997[w] Mineralizable N ppm	Organic P ppm	K ppm	Mn ppm	% organic matter	Mean residue applied (t ha^{-1} dry wt)
Fallow	30.8 C[x]	7.6	283.2 B	12.3 C	0.77 D	—
Austrian winter pea	40.5 B	6.0	281.2 B	12.6 BC	0.81 C	6
Sudangrass	42.6 AB	8.4	284.8 B	14.8 A	0.87 AB	12
Barley	46.5 A	6.3	318.8 A	14.5 A	0.89 A	11
Sweet Corn	44.2 AB	8.5	312.0 A	14.1 AB	0.85 BC	12
		NS				

[w]Soil assayed prior to fertilizing field.
[x]Different letters indicate significant differences to $P \leq 0.05$ level.

When metam sodium was applied to green manure plots, the green manure treatments still suppressed the incidence of Verticillium wilt compared to the metam sodium control (Table 8). This enhancement of disease suppression occurred despite no effect of green manure plus metam sodium on *V. dahliae* soil populations (Table 8). While *V. dahliae* soil populations did not correlate with wilt incidence, colonization of *V. dahliae* in stem tissue did correlate (r = 0.558**). In contrast to *V. dahliae*, soil populations of *F. equiseti* were negatively correlated (r = -0.585**) with wilt incidence.

Mineralized N, Mn, and % organic matter increased following a green manure treatment of sudangrass compared to the non-amended fallow (Table 9). The amount of green manure biomass of sudangrass, corn, and barley applied to soil was similar (11-12 T ha^{-1}) to biomass in Exp. 1 and the percent of organic matter in soil did not differ among these treatments. Similarly, the mineralizable N and Mn also did not differ among these green manure treatments. Yet, the positive yield response of Russet Burbank occurred only following the sudangrass treatment and not with either the corn or barley treatments (Table 7). No significant relationship between yield and quality with *F. equiseti* populations, organic residue, mineralizable N, or Mn was seen.

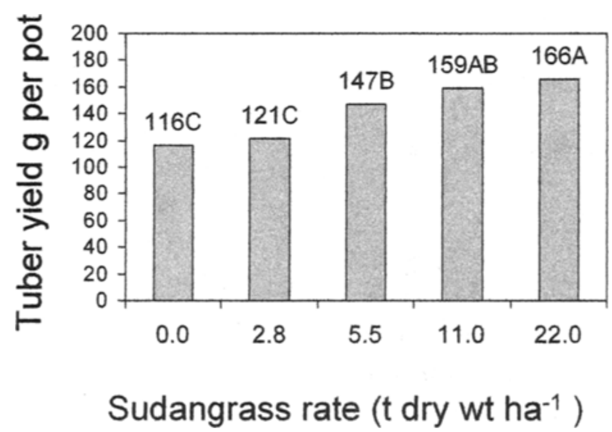

FIGURE 2.
Results of greenhouse study demonstrating effect of sudangrass rates on yield.

Greenhouse Study— Experiment 3

As the rate of sudangrass added to the soil mixture increased from 0 to 22 t ha^{-1}, tuber yield was increased (Figure 2). When 22 t ha^{-1} sudangrass foliage was added to pots in the greenhouse, yields were increased by 43% compared to the non-amended control — a value that did not differ from the 1x rate (11 t ha^{-1}). As the amount of sudangrass added to the soil was increased, populations of *F. equiseti*, *F. solani*, and *F. oxysporum* also increased (Figure 3). None of the plants developed foliar symptoms of Verticillium wilt, and *V. dahliae* was not recoverable from stems. Throughout this study, all plants were fertilized on a weekly basis to maintain maximum fertility, and there were no symptoms of nutrient deficiency.

DISCUSSION

Results of several studies showed that a sudangrass green manure improved both tuber yield and quality of potato beyond the effects of Verticillium suppression.

Although yields were high in the fields where these studies were conducted, the sudangrass treatments still increased both yield and quality of Russet Burbank (a late season variety) but not of Norkotah (an early season variety). These results could not be explained by Verticillium wilt suppression alone. As anticipated, *V. dahliae* colonization of stems correlated positively with wilt incidence. However, the severity of Verticillium was considered low and with a single exception involving sudangrass roots and foliage in the first study, the colonization failed to correlate with either potato yield or quality (Table 4). In these two field studies, Verticillium wilt was not believed to be a significant limiting factor of tuber yield. The only nutrient to correlate both negatively with wilt incidence and positively with yield of tubers >280 g (10 oz) was NO_3-N. However, at no time did petiole assays suggest nutrients to fall below critical levels with any treatment.

Further evidence for the beneficial effects of sudangrass was provided with a greenhouse experiment. When sudangrass was added to pots containing field soil to approximate the amount applied in the field (5-11 t ha^{-1}), yields were again increased (Figure 2). As with the field studies, these yield benefits were unrelated to Verticillium. Tuber yield was a function of the rate of sudangrass incorporated (Figure 2). Yield increases were not related to *V. dahliae* colonization of potato stems or to symptoms of Verticillium wilt. This is additional evidence of the positive benefits from sudangrass that were not explainable by Verticillium suppression. Furthermore, there was also no evidence of nutrient deficiency symptoms. Since fertilizer had been applied on a weekly basis, the likelihood of nutrient deficiency seemed doubtful.

The unique benefit of sudangrass became most evident when comparisons were made with other green manure treatments. With this study, the sudangrass treatment was the only treatment to increase potato yield and quality, and these increases occurred even though other treatments were at least as effective as, if not more effective than, sudangrass for suppressing Verticillium wilt (Table 7).

In the study comparing other green manure treatments with sudangrass an attempt was made to reduce disease severity with a broadcast application of metam sodium at 350 L ha^{-1}. Yet, in spite of the fact that *V. dahliae* populations between treat-

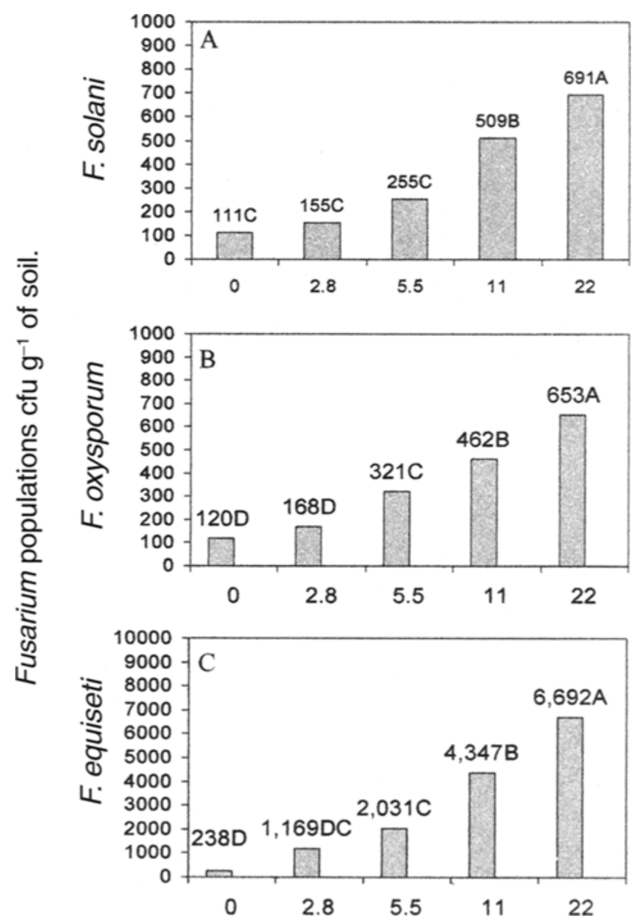

FIGURE 3.
Greenhouse study showing changes in populations of *Fusarium* spp. with different sudangrass rates.

ments did not differ, the sudangrass treatment still produced higher yields than all other treatments by 27% to 60% for tubers in the U.S. #1 category (Table 7). These benefits could not be explained as a result of differences in either soil populations of *V. dahliae* or Verticillium wilt suppression. This is the second study where this phenomenon has been observed.

Similar results were first observed when the effects of a 2-year sudangrass green manure were compared with 2 years of oat, rye, and corn green manures (Davis et al. 1996). As in the present study, the sudangrass treatment provided highest yields of smooth tubers >280 g, and results could not be explained by differential nutrient levels. Since the wilt incidence following sudangrass did not differ between green manures of oat, rye, or corn, results could not be explained by either Verticillium suppression or by a differential phenomenon of nutrition.

Experiment 1 also suggested the occurrence of an additional effect of sudangrass on potato quality. When foliage of sudangrass was removed from field plots as would normally be done with rotations, Verticillium wilt was suppressed (Figure 1, Table 3). With this suppression of Verticillium wilt, the percentage of U.S. #1 tubers >280 g was increased but not yield (yield benefits only occurred following green manure treatments).

In addition to significant effects on potato quality with sudangrass, results also showed that the Trudan-8 variety (a hybrid of sudangrass and sorghum) could be substituted for HS-33 (the clone of sudangrass used most commonly throughout all of our studies) (Table 2). This has value due to a potential benefit for controlling the root knot nematode. Green manures of Trudan-8 have been previously reported to reduce egg populations of both the Columbia root knot nematode (*Meloidogyne chitwoodi*) (Mojtahedi et al., 1993) and the northern root knot nematode (*M. hapla*) (Viaene and Abawi 1998) – both limiting factors of potato production.

The significant increases of nutrients and increased populations of the microbial indicator *F. equiseti* that are reported with a sudangrass green manure fail to explain the effect of sudangrass on potato quality and yield (Tables 6 and 7). Significant increases of mineralizable N and Mn occurred in soil following green manures of sudangrass, barley, and corn, but these nutrient increases did not differ from the effects of either barley or corn. Yet, the sudangrass resulted in increased U.S. #1 yields, whereas barley and corn did not. Similarly, the highest populations of *F. equiseti* occurred following a barley green manure treatment and not sudangrass. Currently we still fail to understand the rationale for the potato yield and quality benefits from a sudangrass green manure. The combined effects of nutrients, however, might conceivably provide many possibilities for yield increases, along with additional knowledge of changes to soil microflora. Both N and P have been shown to have an additive effect on both wilt suppression and increased yields of Russet Burbank potato (Davis et al. 1994c). As a result of our comparative green manure studies and of previous studies (Davis et al. 1996), sudangrass has provided the most consistently high yield responses of U.S. #1 and tubers >280 g for any green manure treatment.

For the purpose of comparisons with earlier work (Davis et al. 1996), and in the interest of achieving maximum benefits from sudangrass, we arbitrarily chose to use two years of a sudangrass green manure treatment. It has never been shown, however, that a minimum of two years is required. To the contrary, more current data (Davis et al. 1997, 2004) shows this not to be true. Subsequent work, directed at making the green manure approach commercially practical, showed that once a suppressive effect had been established, a green manure treatment for a single season could be sufficient to either maintain or to establish the desired effect.

Although one might still argue that even growing a green manure for a single season is not economically feasible, this may still not be a major limitation. Sudangrass is a good forage crop that may be harvested in mid-summer and the re-growth put down in fall as a green manure. Second, a sudangrass green manure can be part of a double cropping system (e.g., Austrian winter peas followed by sudangrass).

Finally, although a more difficult and long-term approach, agricultural policy could be adjusted to encourage grower utilization of all cover crops including sudangrass. Such a policy might solve our problems with over production, increase the price of potatoes, and help nurture the soil for long-term sustainability.

From the perspective of sustainable agriculture, an understanding of the sudangrass effect may have broad implications in systems of potato production. This paper calls attention to benefits of sudangrass and negates the possibility of several factors to explain this phenomenon. Although farmers have been using green manures for many centuries, there is still much that we fail to understand regarding the unique effects of sudangrass.

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